Use of Molecular Oxygen to Reduce EUV-induced Carbon Contamination of Optics

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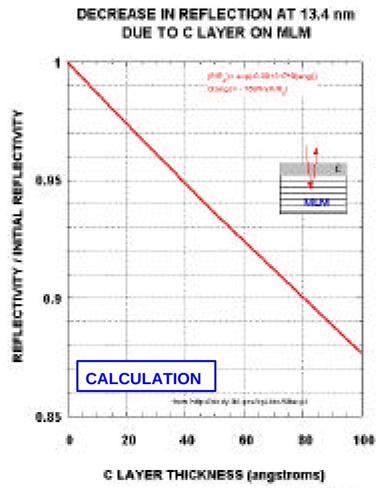
Test Objective

- **Determine <u>approximate</u> C removal rates from Mo/Si multilayer mirrors (MLMs) using O_2 + EUV**
  - **O_2 pressures necessary**
  - **test at representative EUV powers ~ (0.2 - 4) mW/mm^2**
  - **expected cleaning mechanism - gasification of C by reactive oxygen species, details to be determined**
- **Use results as input for ETS operation**
- **The next step: Measurement of real-time O_2 cleaning**
  - **simultaneous processes of C deposition and removal**

C Deposits on EUV Optics Decrease Reflectivity

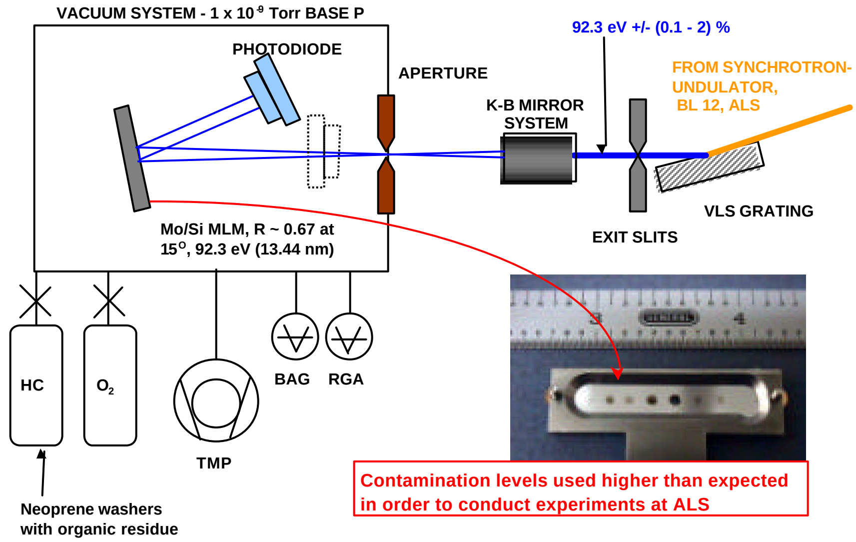
- **Multiple optics increase C effect**
- **C must be cleaned off without degrading optics**
  - **no extreme oxidation**
- **O_2 introduction is simple**
  - **pressure can be measured directly**
- **Real time cleaning possible where it's needed - on illuminated areas of optics**



Experimental

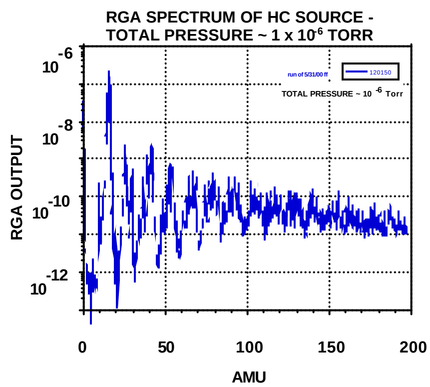
- **Two types of experiments performed at Advanced Light Source (ALS)**
  - **"Deposit and Clean": deposit separate C spots, then clean each with O_2 + EUV at different oxygen pressure, EUV power**
  - **"Coexposure" : Simultaneous C deposition, O_2 + EUV removal**
- **Assumptions**
  - **pulsed nature of ALS OK- average EUV power important**
  - **surrogate hydrocarbon (HC) source mimics high molecular weight HCs in tools**
- **Techniques**
  - **Real time, *in-situ***
    - **EUV reflectivity (R) measurement**
    - **Pressure, RGA measurement (except at pressures > 1 x 10^{-4} Torr)**
    - **Photoemission**
  - ***Ex-situ***
    - **Auger Electron Spectroscopy (AES) sputter-through depth profiling**
- **Contamination levels used higher (~ 100 x) than in ETS in order to conduct experiments at ALS**

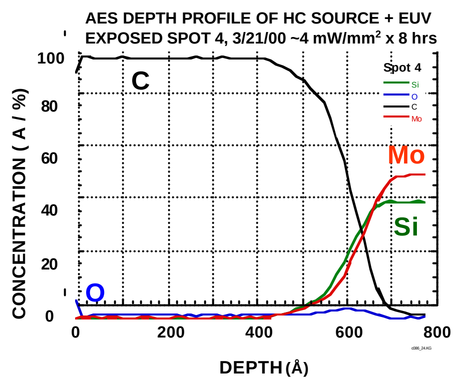
System Schematic



Contamination levels used higher than expected in order to conduct experiments at ALS

HC Source + EUV Produces C Deposits on MLMs

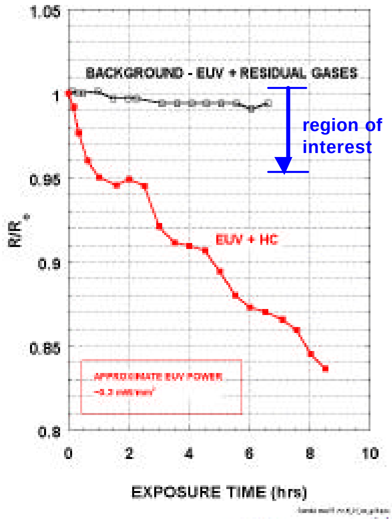




~~Contamination levels used higher than expected in order to conduct experiments at ALS~~

Typical Reduction of MLM Reflectance with HC Source

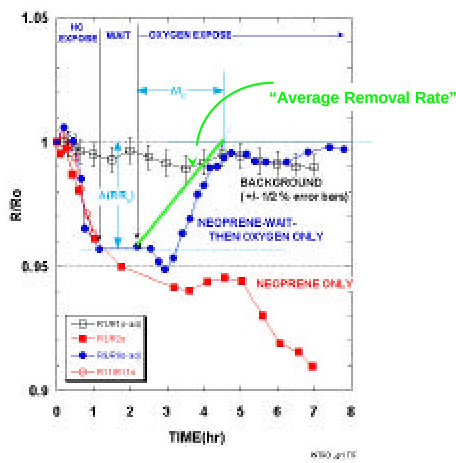
- Data shown as R/R_o, reflectance/original reflectance
- Original reflectances:
  - ~ 0.65 - 0.67 measured *in-situ*
  - ~ 0.67 measured on ALS BL 6.3.2, metrology beamline



"Deposit-Clean" Results: Reflectivity can be Restored by EUV + O_2

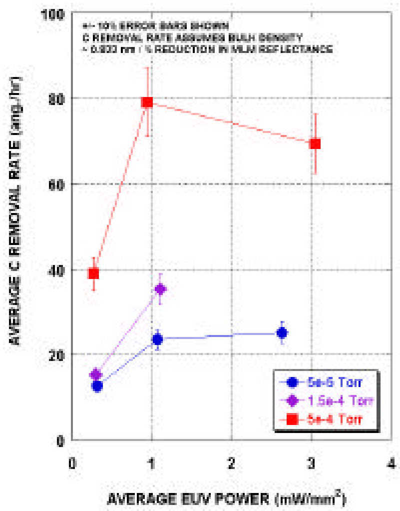
- Several C spots with ~ 4 % R/R_o reduction deposited, then O_2 exposed
- "Average Removal Rate" time computed from time O_2 introduced to time $R/R_o = 1$ reached based on construct shown
- "Average Removal Rate" given by slope of green line

Typical Reflectance Results



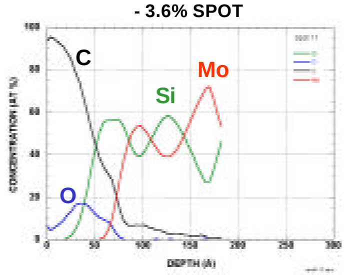
Average Carbon Removal Rates

- Data from “Deposit-Clean” experiments used
- C bulk density, computed R vs thickness from X-ray tables assumed
  - Density of C deposits ~ 0.5-1 x theoretical bulk density (T.B.D.)
- Non-linear dependence of removal on EUV power, O_2 pressure at levels studied
  - cleaning increases faster with pressure than EUV power

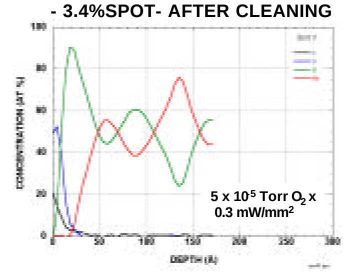


AES Results Show C Removal

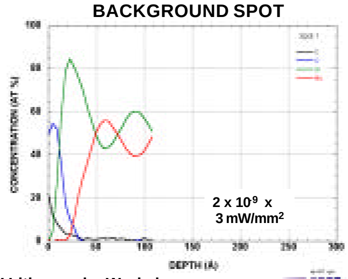
- 3.6% SPOT



- 3.4%SPOT- AFTER CLEANING

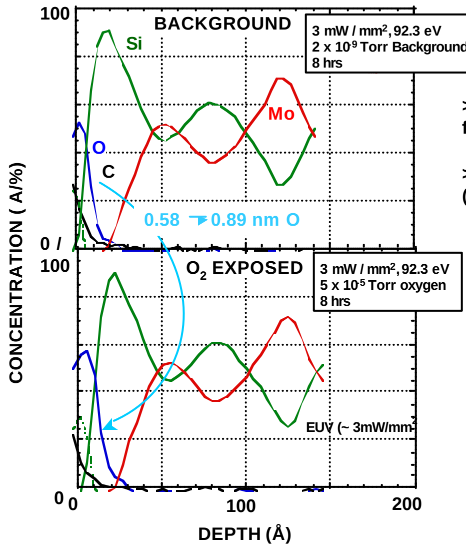


BACKGROUND SPOT



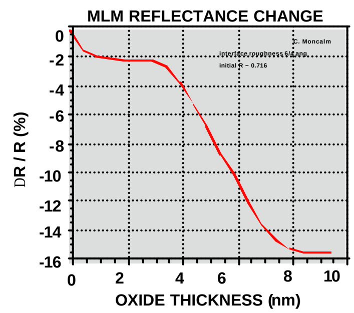
Low Oxygen Risk to Optics:

Only ~ 0.3 nm Oxidation Occurs at 5 x 10^{-5} Torr of Oxygen x 8 hours at 3 mW / mm^2 (92.3eV)



> exposure of a MLM to oxygen at 5 x 10-5 Torr for 35 hours (0.3 mW/mm^2) produced < 1%DR/R

> up to ~ 3 nm of oxide might be tolerable (CALCULATION by Claude Montcalm, LLNL):



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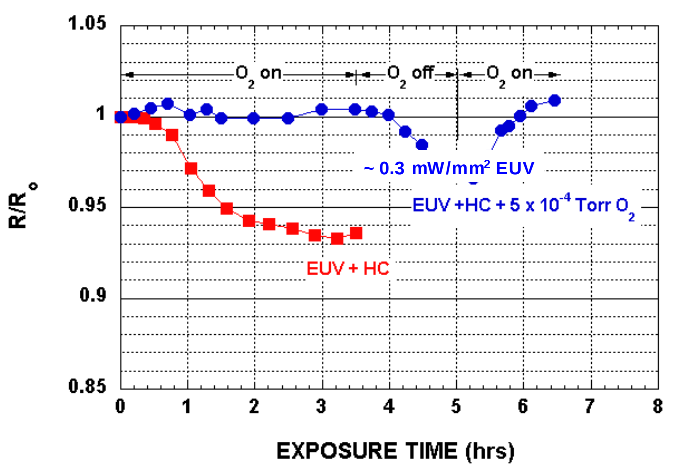
O_2 Coexposure can Prevent C Deposition



R vs t 09_26_00B_gr3.qpc

Summary

- O_2 + EUV Removes C spots
  - up to 7 nm/hr at C theoretical bulk density (T.B.D.) at ~ 5 x 10^{-4} Torr O_2, 3 mW / mm^2 EUV
  - removal rate is not linear with EUV power or pressure
    - dependence on pressure stronger than on EUV power density
- Little additional oxidation of MLM occurs at highest powers used
  - ~ 0.3 nm additional oxide layer thickness with exposure at 5 x 10^{-5} Torr, 3 mW/mm^2 EUV power x 8 hours
  - long-term exposures required to complete data
- Preliminary: Oxygen + EUV coexposure can prevent C buildup at pressures of < 5 x 10^{-4} Torr O_2